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Optimization of the Sizing Process with Grey Relational Analysis

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Abstract
The sizing process is an important one for textile mills and affects the efficiency of the loom machine. In this study, the optimisation of multiple performance characteristics based on the grey relations analysis method, which is a new approach for optimisation of the sizing process was researched using the Taguchi L18 (mixed 3 - 6 level) experimental plan. The process parameters selected: warp yarn count, the viscosity of the sizing solution and the dispatch speed of the warp yarn passing from the sizing machine, were optimised. In the experimental design of Taguchi L18 (mixed 3 - 6 level), the warp yarn count factor was chosen as 3 levels (12, 10 and 8 tex), the viscosity of the sizing solution factor as 3 levels (14, 20, & 24 Ns/m²), and the dispatch speed of the warp yarn passing from the sizing machine factor was selected as 6 levels (40, 50, 60, 70, 80, & 90 m/min). Quality characteristics were determined as the warp yarn strength, and the efficiency of the loom machine. A grey relational grade obtained from the grey relational analysis is used to solve the sizing process with multiple performance characteristics. Optimum levels for the sizing process parameters were determined using the grey relation grade.

Key words: *sizing, orthogonal array, grey relational analysis, optimization.*

Introduction

Sizing is a process before weaving which directly affects the performance of the weaving process. The process' physical length is approximately 60 m. The most important output parameters of the process that will optimise the determination of the levels of the input parameters are an optimisation problem. The Taguchi optimization method reduces the number of experiments, and thus recently using the method has increased for the solution of engineering optimisation problems. In the classical Taguchi applications, quality characteristics are examined one by one; for each characteristic, the optimum level of inputs is determined, but the Taguchi Method based on grey relational analysis, which is a new approach, at least two and more quality characteristics can be considered collectively . Accordingly the optimum quality level desired according to the characteristics of the input parameters can be determined. The Taguchi method's steps for one output:1. Experiment Design and Execution 2. SignaltoNoise Ratio (S/N) Calculation & 3. Optimal Factor Levels Determination. The steps of the Taguchi method based on grey relation analysis for multiple outputs: 1. Experiment Design and Execution, 2. SignaltoNoise Ratio (S/N) Calculation 3. Establishment of Decision Matrix, 4. Normalisation of Data, 5.Weighting of Normalised Data, 6. Ranking Points' Calculation of the Alternatives, and 7. Optimal Factor Level Determination [1].

The Taguchi Method based on Grey relational analysis is applied in various engineering sciences. for example, Lin and Lin (2002) in the electrical discharge machining (EDM) process, Tosun (2006) - optimising the drilling process parameters for work piece surface roughness and burr height, Kopac and Krajnik (2007) - optimising the robust design of flank milling parameters, Kuo, Yang and Huang (2008) - to solve multi-response simulation problems, Kuo and Tu (2009) to improve the quality control strategy for calendering, Eşme, Bayramoğlu and Aydın (2009) - to optimize galetaj process parameters affecting the surface roughness and microhardness (forward speed, number of passes, galetaj speed and compression force), Su, Chen, Ma and Lu (2011) - optimising of yarn evenness and yarn strength, Yıldırım (2011) - determining of the quality characteristics of washing machine models and the factors affecting the level of the best factor, and the Grey Relational Analysis method was used in [1 - 8]. In optimisation with grey relational analysis, output parameters can be weighted for the degree of importance. Work is usually the output parameters on an equal weighting [2, 3, 9]. However, there are some studies giving different weights to outputs [10 - 13].

The Taguchi optimisation technique based on grey relation analysis, which is a new multicriteria optimisation method for textile, was applied, and the best input parameters for specified performance characteristics of the sizing process could be determined. In this study, different weights (0.3 - 0.7; 0.5 - 0.5;0.7 - 0.3) are given the two output parameters to view the results of the method's weighting steps, and optimisation results were compared.

Material

In the study, during the pre-trial process in the weaving, sizing of the fine yarn count was found to be more important than thicker yarns. After this determination, fine yarns produced for shirting and cotton material (because it is especially used for short staple spinning) were decided to be used. Cotton yarns (12, 10 and 8 tex) were selected.

Methods

Determiniation of input parameters to be optimized and multiple performance characteristics

In this study, the Taguchi method based on Grey Relation Analysis was applied. Therefore the sizing process parameters to be optimised and the best performance characteristics were firstly determined. The input factors affecting the sizing process and the outputs obtained from the process are given in ***Table 1***.

The speed input expresses the warp yarn passing on the drying cylinder in the sizing machine. Slow or fast passing on the drying cylinders in the sizing machine affects moisture content on the yarn. When the yarn has too much moisture or is too

Table 1. Factors affecting the sizing process and the sizing process outputs obtained from the process [14].

Test parameters (input variables)	Outputs (response variables)
Speed, m/min	Efficiency, %
Viscosity, Ns/m^2	Strength, cN/tex
Yarn count, tex	

Table 2. Selected design of experiments L18 (mixed 3 - 6 level) [14, 15].

Factor No. (Code)	Factors	Level number	Levels
1(A)	Speed m/min	6	40, 50, 60, 70, 80, 90
2(B)	Viscosity, Ns/m^2	3	14, 20, 24
3(C)	Yarn count, tex	3	12, 10, 8

dry, it may lead to efficiency losses in the weaving machine. The viscosity input determines the fluidity of the sizing solution. Low or high sizing solution viscosity causes some problems for the further process. The yarn count input, yarn type and yarn fineness in the appropriate machine setting are determined by selecting a suitable sizing agent for the sizing yarns. The output process parameters selected, shown in ***Table 1,*** are expressed below.

a) Warp yarn strength: In this study, the warp yarn strength is selected as the first output parameter. The weaving process is the next step after sizing. The sized yarns will be exposed in order to be resistant to the weaving process, as having the highest possible strength is desired. In this paper, for the measurement of yarn strength, TITAN strength test apparatus (origin from England) was used and tests performed according to the EN ISO 2062 standard.
b) The efficiency of the weaving machine is selected as the second output parameter. Behaviour against forces of sized yarns in the weaving machine (i.e. warp yarn breakage, hence the number of stoppages of the weaving machine) can be expressed as weaving machine efficiency. In the study, weaving machine efficiency was determined by measuring warp yarn breakage over 1000 m. A Vamatex weaving machine (2002 brand, origin from Italy) was used in the study.

Preparation of the test plan

In this study, the input parameters and levels selected are shown in ***Table 2***. According to the schedule in the full factorial design of experiments, the necessary number of experiments will be 54. However, the number of experiments can be reduced to 18 by the Taguchi Method. This method, supported by the literature, can obtain overall results by a lesser test. According to the factors and levels in the Taguchi experimental design selected, the L18 (mixed 3 - 6 level) orthogonal layout was decided. ***Table 2*** shows the design. In this study, a total of 18 experiments were applied.

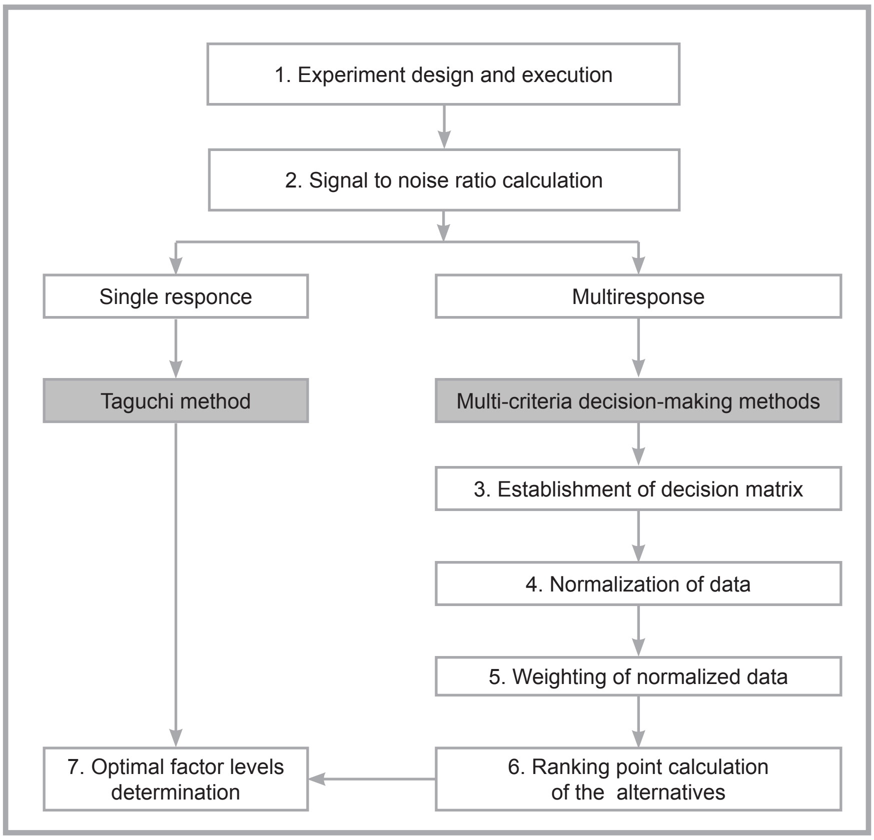

Figure 1. *Application procedure of the Taguchi method based on grey relational analysis [1, 8].*

Grey relationship analysis method

The multiple performance response is converted to a single one using Multi-criteria decision-making methods with the Taguchi method. In this way, the problem would be formed into an optimisation problem with a single response. In ***Figure 2***, the application procedure of the Taguchi method based on grey relational analysis is given. According to this figure, in steps 1, 2 & 7, the general procedure of the Taguchi method is given, and in steps 3 - 6 that of the Multi-criteria decision making method [1, 8].

Grey relational analysis method steps of the calculation are as follows.

Step 1. The reference sequence of length n is as follows in ***Equation 1.***

$$x_0 = (x_0(1), x_0(2), x_0(3), ..., x_0(n)) \quad (1)$$

Step 2. Data to be normalised

Normalisation in the theory of grey system projects is called Grey Relational Generating. The normalisation of data in one of the most commonly used methods is preprocessing linear data. Being considered in the normalisation of the factor series is which criteria („The Larger – The Better", „The Smaller – The Better" and "The Nominal – The Better") reflect the feature of the series. For example, if the smaller values are desired in the series, the linear normalization values should be closer "1", if the bigger values are desired in the series, the linear normalization values should be closer "0".

In the "The Larger – The Better", normalization is as follows in ***Equation 2***

$$x_i(k) = \frac{x_i^o(k) - \min x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)} \quad (2)$$

$x_i^o(k)$, the i series is the original value of the k. order; $x_i(k)$ the value which is the i series and k order after normalisation, $\min x_i^o(k)$ the minimum value in the i series, and $\max x_i^o(k)$ the maximum value in the i series.

In the "The Smaller – The Better", normalisation is as follows in ***Equation 3.***

$$x_i(k) = \frac{\max x_i^o(k) - x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)} \quad (3)$$

In the "The Nominal – The Better", Normalization is as follows in ***Equations 4.***

$$x_i(k) = 1 - \frac{\left|x_i^o(k) - x^o\right|}{\max x_i^o(k) - x^o} \quad (4)$$

Here, x^o the ideal desired value indicates.

Step 3. The m number series is compared with the x^o series, defined in ***Equation 5***.

$$x_i = (x_i(1), x_i(2), x_i(3), ..., x_i(n)) \quad i = 1, 2, 3, ..., m \quad (5)$$

Step 4. k shows the k order over the length of the n series. $\varepsilon(x_0(k), x_i(k))$ is the grey relational coefficient in the k order, and can be calculated in ***Equations 6, 7, 8 & 9***.

$$\varepsilon(x_0(k), x_i(k)) = \frac{\Delta_{\min} + \xi\Delta_{\max}}{\Delta_{0i}(k) + \xi\Delta_{\max}} \quad (6)$$

$$\Delta_{0i} = |x_0(k) - x_i(k)| \quad (7)$$

$$\Delta_{\min} = \min_j \min_k |x_0(k) - x_i(k)| \quad (8)$$

$$\Delta_{\max} = \max_j \max_k |x_0(k) - x_i(k)| \quad (9)$$

$\xi \in (0,1)$ is the distinguishing coefficient in 0 - 1, j = 1, 2, …, m; k = 1, 2, ..., n. The purpose of ξ is to adjust the difference between Δ_{0i} and $\Delta_{\max}$. Studies indicated that when different distinguishing coefficients are adopted, the grey relational coefficient results are always the same [1, 16, 17].

Step 5. If impact on the performance of the output is equal, Grey Relational Degree is calculated by ***Equation 10***.

$$\gamma(x_0, x_i) = \frac{1}{n}\sum_{k=1}^{n} \varepsilon(x_0(k), x_i(k)) \quad (10)$$

Different levels of performance effects (in weight) should be taken into account in the calculation of this weight. If the outputs have equal weight for quality, the total weight must be equal to "1". Thus two outputs share the total weight as equal (0.5 - 0.5). If one of the outputs has more influence than the other, its weight is larger. ***Equation 11*** is used for calculation of the weighted grey relationship degree.

$$\gamma(x_0, x_i) = \frac{1}{n}\sum_{k=1}^{n} W_k \; \varepsilon(x_0(k), x_i(k)) \qquad \sum_{1}^{n} W_k = 1 \quad (11)$$

$\gamma(x_0, x_i)$ is a measure of the geometric similarity between x_i in a grey system and x_0 reference sequences. The size of the grey relational degree is an indication that there is a strong relationship between x_i and x_0. If two the series compared are the same, the grey relational grade is found as 1. The grey relational grade shows that the reference series are somewhat similar with the series compared [3, 9, 18 - 22].

In this study, 3 different weights were chosen: the weaving efficiency (0.5) – yarn strength (0.5), efficiency (0.7) – strength (0.3) and efficiency (0.3) – strength (0.7).

Step 6. Determination of the new levels of the test factors.

Step 7. Performing an ANOVA test.

Step 8. Performing a confirmation test. The grey relational grade η estimated using the optimal level of the parameters is calculated as ***Equation 12***. Where η_m is the total mean of the grey relational grade, η_i the grey relational grade at the optimal level, and j is the number of parameters that significantly affect the multiple performance characteristics.

$$\eta = \eta_m + \sum_{i=1}^{j}(\eta_i - \eta_m) \quad (12)$$

Application of the grey relational analysis method to the sizing process

The Taguchi L18 (mixed 3 - 6 level) experimental plan and results of the experiments are shown in ***Table 3***. In the first row, factors affecting the process (A - C) and response variables are given. The first column in the table refers to the experiment's number. In the last two columns, the results of experiments carried out by the experimental study are given.

Minitab 15® software program was used for application of the Taguchi Method. The grey relational grade, which is calculated by ***Equation 10,*** is placed from the largest to the smallest in the first column. The grey relational grade in the second and third columns is calculated by ***Equation 11***. As a result of this sorting, experiments with a combination of the largest grey relational grade has the best multi-performance characteristics. In ***Table 4*** (seee page 52), the grey relational grade is given for the weighted efficiency (0.5) – strength (0.5), weighted efficiency (0.7) – strength (0.3), weighted efficiency (0.3) – strength (0.7). Ordering from the largest to the smallest is also seen in ***Table 4***.

Table 3. *Results of the experiments for the sizing process [14].*

Experiment number	Experiment parameters (Input variables)			Outputs (Response variables)	
	A (Speed, m/min)	B (Viskostiy, Ns/m²)	C (Yarn count, tex)	Efficiency, %	Strength, cN/tex
1	40 (1)	14 (1)	12 (1)	61.3	33.59
2	40 (1)	20 (2)	10 (2)	84.8	37.78
3	40 (1)	24 (3)	8 (3)	52.9	53.34
4	50 (2)	14 (1)	12 (1)	72.6	32.46
5	50 (2)	20 (2)	10 (2)	86.3	35.22
6	50 (2)	24 (3)	8 (3)	78.9	34.49
7	60 (3)	14 (1)	10 (2)	71.2	30.32
8	60 (3)	20 (2)	8 (3)	83.3	34.50
9	60 (3)	24 (3)	12 (1)	69.5	33.81
10	70 (4)	14 (1)	8 (3)	81.9	32.39
11	70 (4)	20 (2)	12 (1)	87.3	35.26
12	70 (4)	24 (3)	10 (2)	80.9	29.55
13	80 (5)	14 (1)	10 (2)	79.8	33.52
14	80 (5)	20 (2)	8 (3)	63.1	34.61
15	80 (5)	24 (3)	12 (1)	86.8	34.37
16	90 (6)	14 (1)	8 (3)	78.5	35.00
17	90 (6)	20 (2)	12 (1)	77.9	32.10
18	90 (6)	24 (3)	10 (2)	76.9	31.88

Table 4. Grey relational grade for the outputs of efficiency and strength and sorting from largest to smallest with weighting [14].

Experiment number	Grey relational grade					
	Weighted efficiency 0.5 – strength 0.5		Weighted efficiency 0.7 – strength 0.3		Weighted efficiency 0.3 – strength 0.7	
	result	order	result	order	result	order
1	0.56	18	0.28	18	0.28	18
2	0.77	4	0.42	4	0.35	2
3	0.75	5	0.33	14	**0.43**	**1**
4	0.62	14	0.33	13	0.29	14
5	0.77	3	0.43	3	0.34	4
6	0.68	9	0.36	9	0.32	8
7	0.59	16	0.31	15	0.28	17
8	0.73	6	0.40	5	0.33	6
9	0.60	15	0.31	16	0.29	15
10	0.70	7	0.38	6	0.32	9
11	**0.78**	**1**	**0.44**	**1**	0.35	3
12	0.67	11	0.37	7	0.30	12
13	0.68	8	0.37	8	0.31	10
14	0.57	17	0.29	17	0.28	16
15	0.77	2	0.43	2	0.34	5
16	0.68	10	0.36	10	0.32	7
17	0.66	12	0.35	11	0.30	11
18	0.65	13	0.35	12	0.30	13

Table 5. Calculation of new levels for factors of speed, viscosity and yarn count.

Factor and its level	New level		
	Weighted efficiency 0.5 – strength 0.5	Weighted efficiency 0.7 – strength 0.3	Weighted efficiency 0.3 – strength 0.7
A1	0.6921	0.3411	0.3510
A2	0.6890	0.3718	0.3173
A3	0.6419	0.3416	0.3003
A4	0.7179	0.3959	0.3220
A5	0.6758	0.3623	0.3135
A6	0.6614	0.3551	0.3063
B1	0.6385	0.3393	0.2992
B2	0.7132	0.3864	0.3268
B3	0.6874	0.3582	0.3292
C1	0.6651	0.3562	0.3089
C2	0.6891	0.3740	0.3151
C3	0.6849	0.3537	0.3312

Table 6. New levels calculated for the factors of speed, viscosity and yarn count.

Weights	Factors	Levels						Max-min
		1	2	3	4	5	6	
Weighted efficiency 0.5 – strength 0.5	A	0.6921	0.6890	0.6419	**0.7179**	0.6758	0.6614	**0.0760**
	B	0.6385	**0.7132**	0.6874	-	-	-	0.0747
	C	0.6651	**0.6891**	0.6849	-	-	-	0.0240
Weighted efficiency 0.7 – strength 0.3	A	0.3411	0.3718	0.3416	**0.3959**	0.3623	0.3551	**0.0548**
	B	0.3393	**0.3864**	0.3582	-	-	-	0.0471
	C	0.3562	**0.3740**	0.3537	-	-	-	0.0202
Weighted efficiency 0.3 – strength 0.7	A	**0.3510**	0.3173	0.3003	0.3220	0.3135	0.3063	**0.0508**
	B	0.2992	0.3268	**0.3292**	-	-	-	0.0300
	C	0.3089	0.3151	**0.3312**	-	-	-	0.0223

A grey relational grade graph is shown in ***Figure 2***. As is seen in ***Figure 3.a***, in experiment No. 11, the grey relational grade is the highest for the weighted efficiency (0.5) – strength (0.5). As is seen in ***Figure 2.b***, in experiment No. 11, the grey relational grade is the highest for weighted efficiency (0.7) – strength (0.3). As is seen in ***Figure 2.c***, in experiment No. 3, the grey relational grade is the highest for weighted efficiency (0.3) – strength (0.7).

After calculating the grey relational grade, new levels of experiment factors are determined. Calculation of the new level of the factors is provided in ***Table 5*** collectively.

In ***Table 6*** new calculated levels of the factors are given. The first column of the Table represents factors and the first line represents the levels. In the last column the difference between maximum and minimum levels are given. Looking at the charts, the highest level of factors gives the optimum process level. As understood from the table, the forth level of (Speed) factor A, the second level of factor B (viscosity), and the second level of factor C (Yarn count) are the highest grey relational grades for weighted efficiency (0.5) – strength (0.5) . Accordingly the optimal process parameters are determined as A4B2C2. A4B2C2 is not included in the study's design experiment (***Table 3***). Hence the optimum process conditions are 70 m/min of the warp yarn, 20 Ns/m^2 viscosity and 10 tex yarn count. In the last column of the chart, the biggest difference between the levels of the factors is in A (Speed), which means the most effective is factor A (Speed), influencing the quality parameter in the sizing process parameters for these three factors.

For weighted efficiency (0.7) – strength (0.3), the optimal process parameters are determined as A4B2C2 (***Table 4*** is not included in this experiment). Thus the optimum process conditions are 70 m/min, 20 Ns/m^2 viscosity and 10 tex. In the last column of the chart, the biggest difference between the levels of the factors is in A (Speed), which means the most effective is factor A (Speed), influencing the quality parameter in the sizing process parameters, for these three factors. For weighted efficiency (0.3) – strength (0.7), the optimal process parameters are determined as A1B3C3. ***Table 3*** includes the A1B3C3 combination as experiment number 3. The optimum process conditions are 40 m/min of the warp yarn, 24 Ns/m^2 viscosity and 8 tex yarn count for weighted efficiency 0.7 – strength 0.3. In the last column of the chart, the biggest difference between the levels of the factors is in A (Speed), which means the most effective factor is A (Speed), influencing the quality parameter in the sizing process parameters for these three factors.

In ***Figure 3*** (see page 54), the grey relational grade graphics of the sizing process parameters levels are given. Here the optimum parameter levels are shown for weighted efficiency 0.5 – strength 0.5 in ***Figure 3.a***. In ***Figure 3.b***, the optimum parameter levels are given for weighted efficiency 0.7 – strength 0.3. Optimum parameter levels are shown for weighted efficiency 0.3 – strength 0.7 in ***Figure 3.c***.

After these assessments, an ANOVA test is performed. The factor that has the highest F value is determined as the most effective, influencing process parameter performance. The ANOVA test of the grey relational grade for weighted efficiency 0.5 – strength 0.5 is given in ***Table 7.a*** (see page 54), in which the output parameter with the highest F value is shown as B (Viscosity). The contribution value in % also supports the result. The ANOVA test of the grey relational grade for weighted efficiency 0.7 – strength 0.3 is given in ***Table 7.b***. In the table, the output parameter with the highest F value is shown as B (Viscosity). The contribution value in % also supports the result. The ANOVA test of the grey relational grade for weighted efficiency 0.3 – strength 0.7 is given in ***Table 7.c***, in which the output parameter with the highest F value is shown as B (Viscosity).

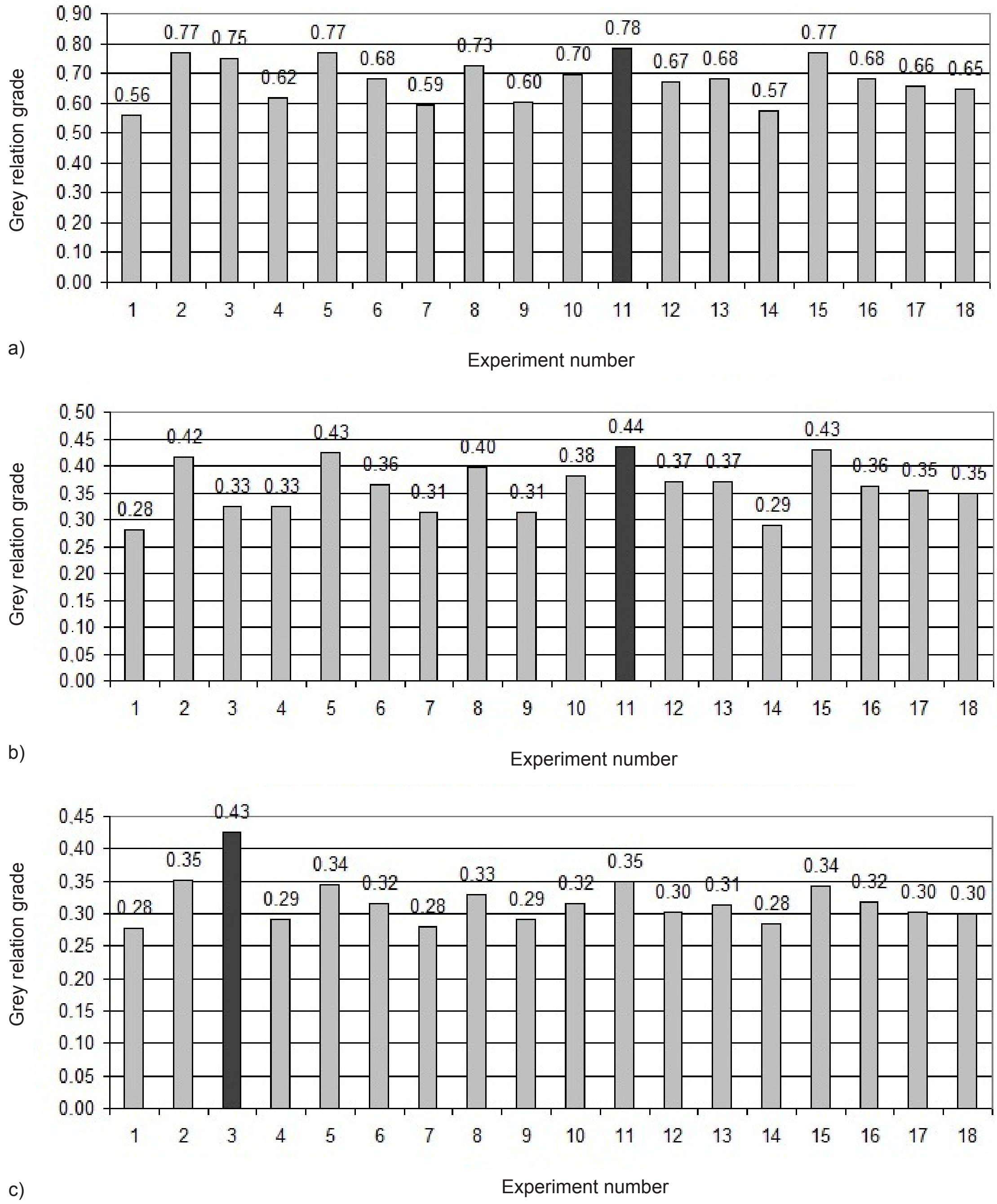

Figure 2. *Grey relational grade graph for the outputs of efficiency and strength; a) weighted efficiency (0.5) – strength (0.5), b) weighted efficiency (0.7) – strength (0.3), c) weighted efficiency (0.3) – strength (0.7).*

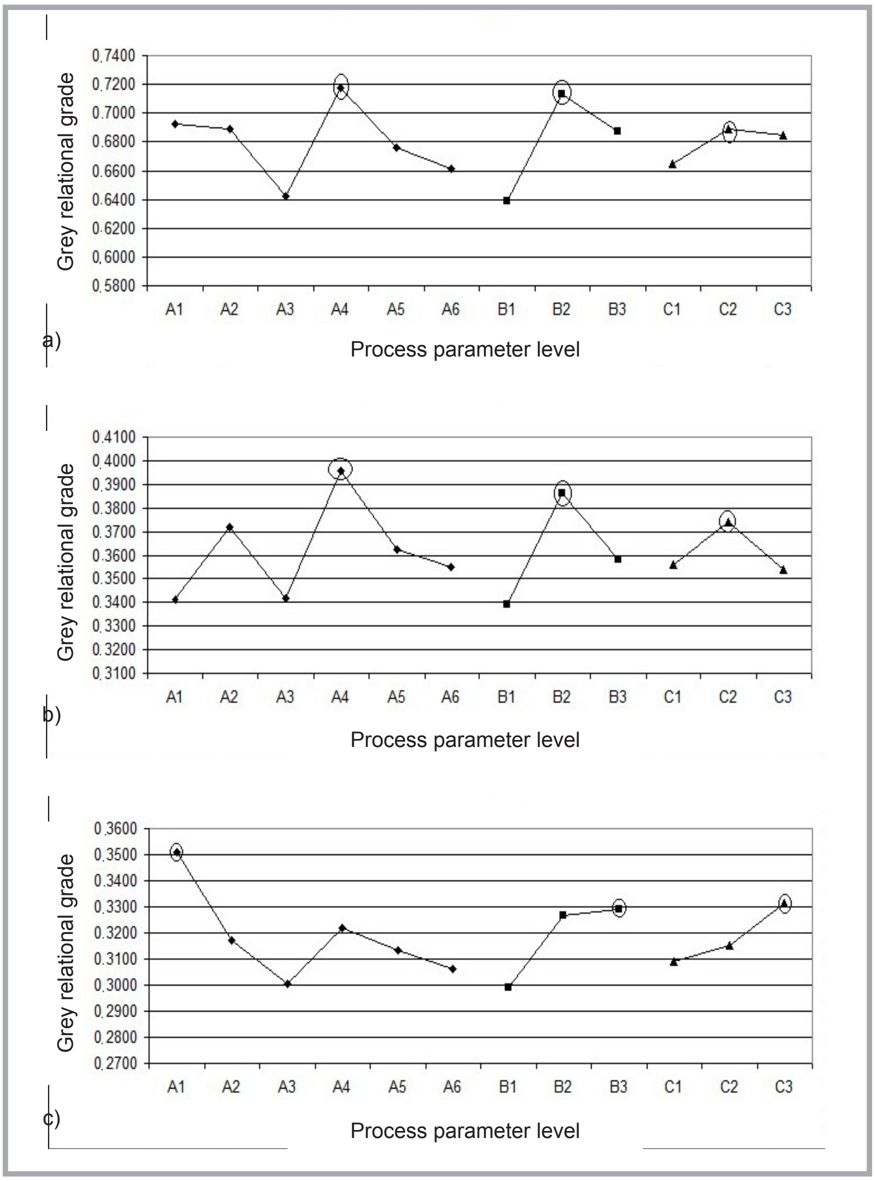

Figure 3. *Graph of sizing process parameters; A) speed, B) viscosity, C) yarn count); a) weighted efficiency 0.5 – strength 0.5, b) weighted efficiency 0.7 – strength 0.3, c) weighted efficiency 0.3 – strength 0.7.*

Table 7. *ANOVA test of the grey relational grade for different weighted efficiency – strength.*

Weights	Source	Analysis of variance for means					
		DF	Seq SS	Adj SS	Adj MS	F	Contribution, %
a) Weighted efficiency 0.5 – strength 0.5	A	5	0.010628	0.010628	0.002126	0.29	12.06493
	B	2	0.017344	0.017344	0.008672	1.19	19.68895
	C	2	0.001911	0.001911	0.000956	0.13	2.16937
	Residual error	8	0.058211	0.058211	0.007276	-	66.08128
	Total	17	0.088094	-	-	-	-
b) Weighted efficiency 0.7 – strength 0.3	A	5	0.006419	0.006419	0.001284	0.44	16.89255
	B	2	0.006729	0.006729	0.003364	1.15	17.70836
	C	2	0.001463	0.001463	0.000731	0.25	3.85010
	Residual error	8	0.023388	0.023388	0.002924	-	61.54899
	Total	17	0.037999	-	-	-	-
c) Weighted efficiency 0.3 – strength 0.7	A	5	0.004733	0.004733	0.000947	0.64	21.92930
	B	2	0.003340	0.003340	0.001670	1.12	15.47514
	C	2	0.001591	0.001591	0.000796	0.53	7.37154
	Residual error	8	0.011919	0.011919	0.001490	-	55.22402
	Total	17	0.021584	-	-	-	-

In the study, once the optimal level of the parameters is found, the final step is to predict and verify the improvement of the output parameters using the optimal level of the input parameters. The prediction and experiment grey relational grades with the optimal parameters are calculated using ***Equation 12***. ***Table 7.a*** shows the results of the confirmation experiment using the optimal parameters for weighted efficiency 0.5 – strength 0.5. As shown in ***Table 7.a***, yarn strength is improved from 33.59 to 44.79 cN/tex, Weaving efficiency is improved from 61.3 to 71.8%, which clearly shows that the multiple performance characteristics in the sizing process are greatly improved by using of Taguchi based on the grey relational analysis method.

Table 8.b shows the results of the confirmation experiment using the optimal parameters for weighted efficiency 0.7 – strength 0.3. As shown in ***Table 8.b***, yarn strength is improved from 33.59 to 44.79 cN/tex and weaving efficiency is improved from 61.3 to 71.8%.

Table 8.c shows the results of the confirmation experiment using the optimal parameters for weighted efficiency 0.3 – strength 0.7. As shown in ***Table 8.c***, the strength is improved from 33.59 to 53.34 cN/tex and weaving efficiency is down from 61.3 to 52.9%. Decreases in the weaving efficiency cannot be considered as important because the output of yarn strength is more important than weaving efficiency in weighting (weighted efficiency 0.3 – strength 0.7).

The results show clearly that the weighted efficiency 0.3 – strength 0.7 and weighted efficiency 0.5 – strength 0.5 show improvement in the grey relational grade, which means that efficiency and strength outputs have same weight for optimisation of the sizing process.

Conclusions

In this study, grey relational analysis as a multicriteria optimisation technique is used to optimise the sizing process. It uses Taguchi Design Models. In this study, the Taguchi L18 (mixed 3 - 6 level) experimental design was applied. The effect on the weaving machine efficiency and warp strength of the inputs affecting the sizing process: the speed of warp yarn passing from sizing machine, viscosity and warp yarn count were investigated using the experimental design. In this

Table 8. Results of sizing performance using the initial and optimal parameters for different weighted efficiency – strength.

Weights		Initial process parameters	Optimum process parameters	
			prediction	experiment
a) Weighted efficiency 0.5 – strength 0.5	Level	A1B1C1	A4B2C2	A4B2C2
	Strength, cN/tex	33.59	-	44.79
	Efficiency, %	61.30	-	71.80
	Grey relational grade	0.56	0.76	0.71
	Improvement of the grey relational grade		0.15	
b) Weighted efficiency 0.7 – strength 0.3	Level	A1B1C1	A4B2C2	A4B2C2
	Strength, cN/tex	33.59		44.79
	Efficiency, %	61.30		71.80
	Grey relational grade	0.28	0.43	0.35
	Improvement of the grey relational grade		0.07	
c) Weighted efficiency 0.3 – strength 0.7	Level	A1B1C1	A1B3C3	A1B3C3
	Strength, cN/tex	33.59		44.79
	Efficiency, %	61.30		71.80
	Grey relational grade	0.28	0.37	0.35
	Improvement of the grey relational grade		0.15	

examination, applying grey relational analysis, multiple responses performance criteria converted to single response performance criteria were obtained in the optimum experimental design. Weaving efficiency and yarn strength outputs have the same weight for optimisation of the sizing process. According to the analysis results, grey relational analysis was proposed with the optimum test combination A4B2C2 and confirmation tests performed. The optimum test combination is 70 m/min speed, viscosity 20 Ns/m^2 and yarn count 10 tex.

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